Properties of Gravity Waves Inferred from AIRS Radian

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Chris Barnet *NOAA/NESDIS*

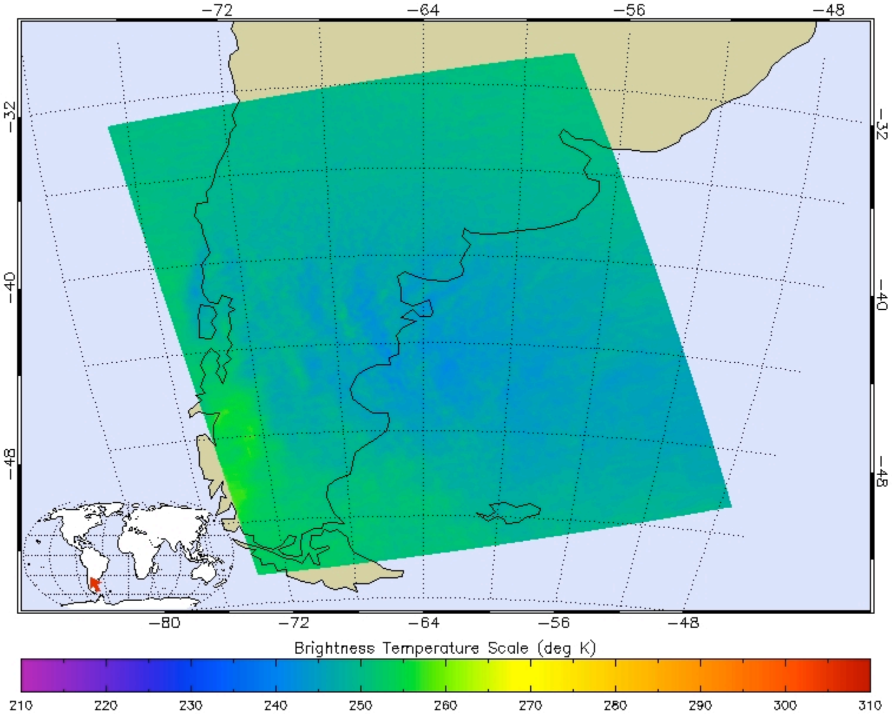
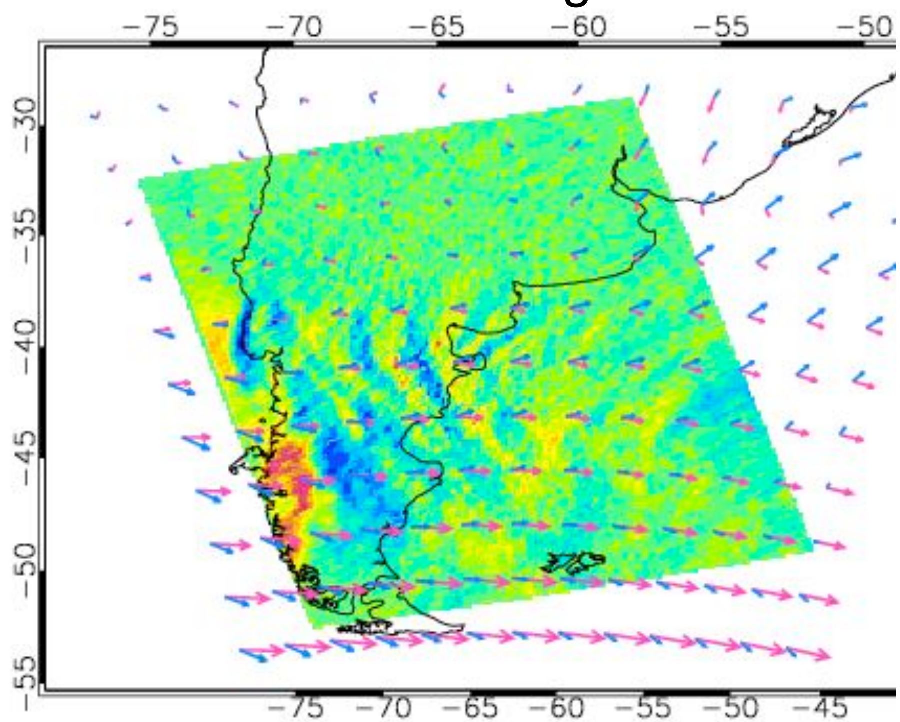


Image courtesy of Sung Yung Lee – JPL

AIRS radiance with background subtra

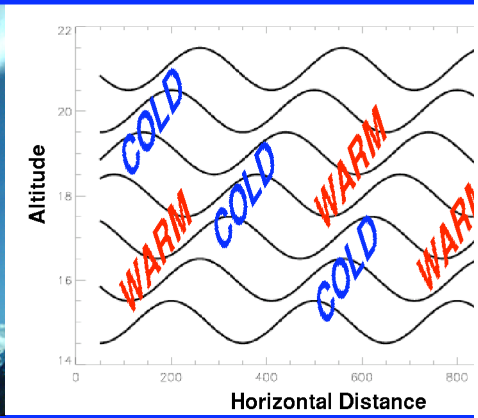


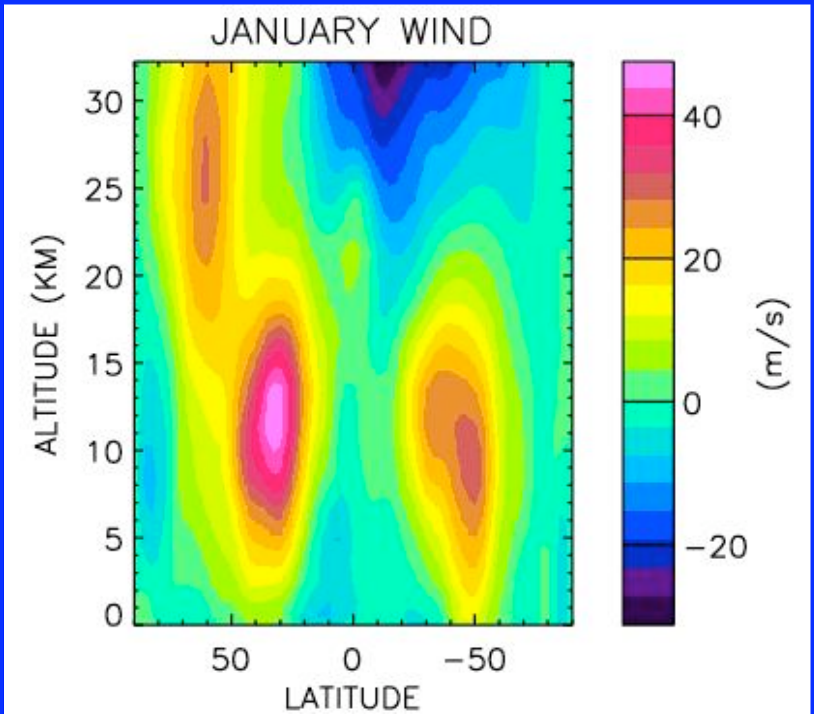
Study waves in L1B radiances for highest horizontal resolution.

Alexander and Barnet, 2006: submitted to J

Global Effects of Gravity Waves

- Ice cloud formation with subsequent effects on:
  - Stratospheric dehydration in the tropics
  - Polar ozone loss
  - Cirrus radiative effects



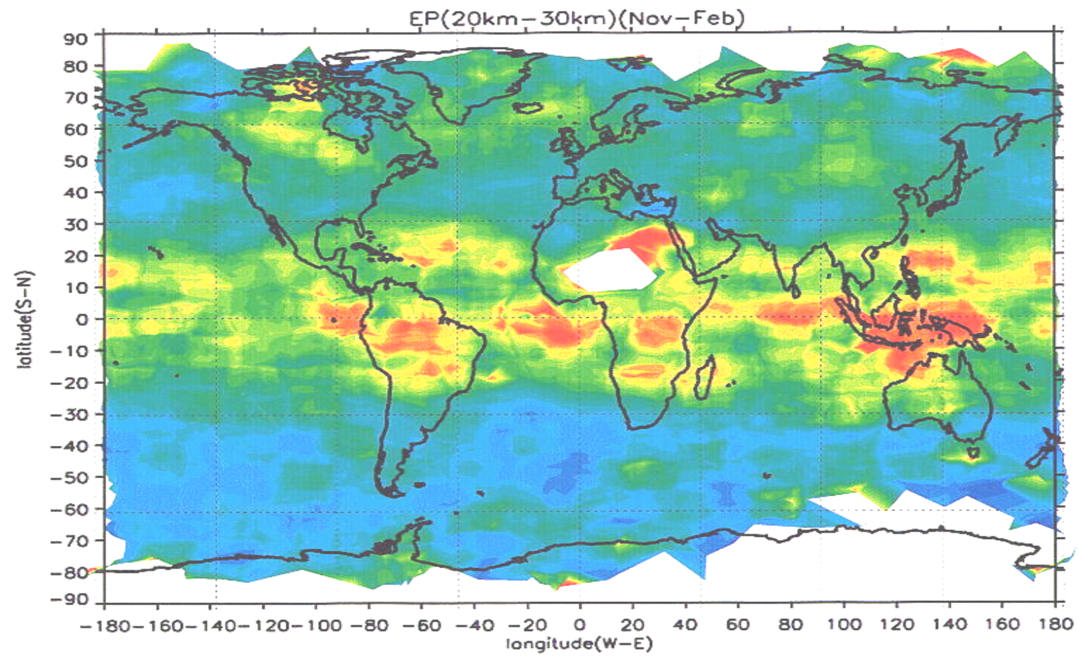


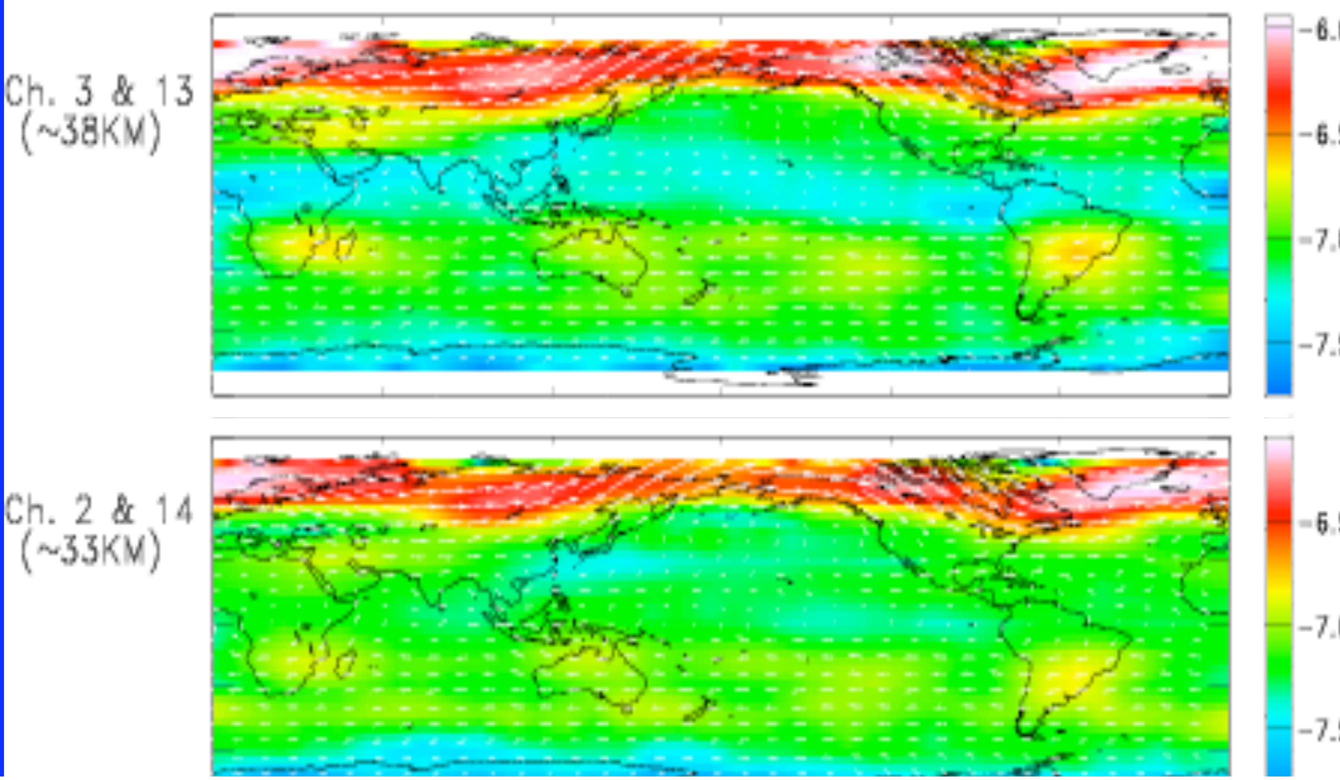
- Driving the observed zonal mean circulation:
  - QBO in stratosphere winds
  - Drag force on the winter jet
  - Timing of summer easterlies

This process currently parameterized in most global models.
Observational constraints needed.

GPS Gravity Wave Potential Energy

Short-Vertical Scale $|T'|^2$
(Tsuda et al., JGR, 2000)
max $|T'|$ ~ 2K

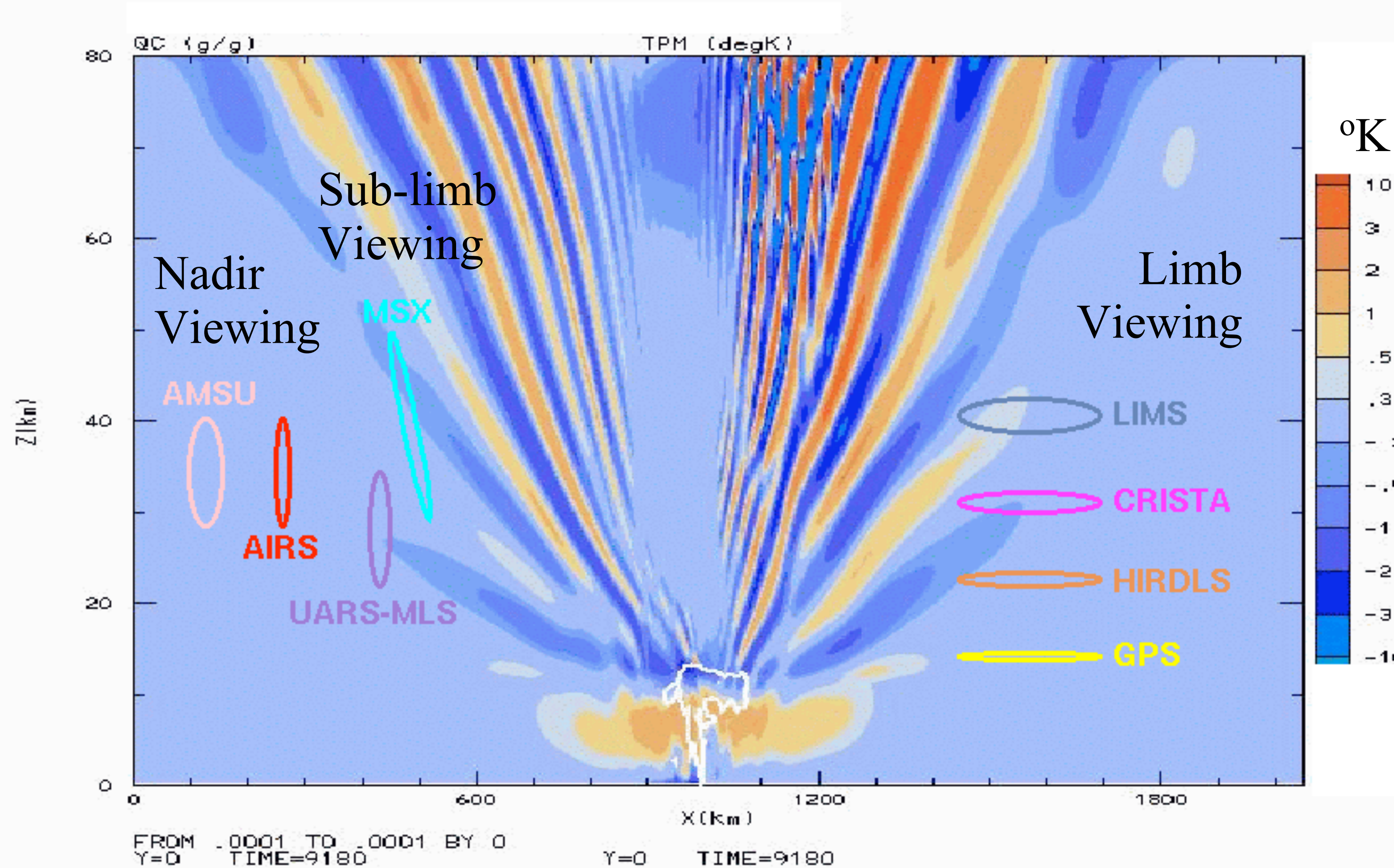




UARS-MLS Gravity Wav Temperatur Variance

Long-Vertical Scale
(Wu and Waters, 1
max $|T'|$ ~ 0.2K

Effective Weighting Functions
for gravity wave observations
(schematic)



• Probability of Observation ~ 1 / C_{gz}

Fast waves are harder to observe.

FAST = Large $C_{gz} \sim \omega / m \sim C_h\, k / m$

FAST ~ **high frequency,**
long vertical scale,
short horizontal scale,
high phase speed.

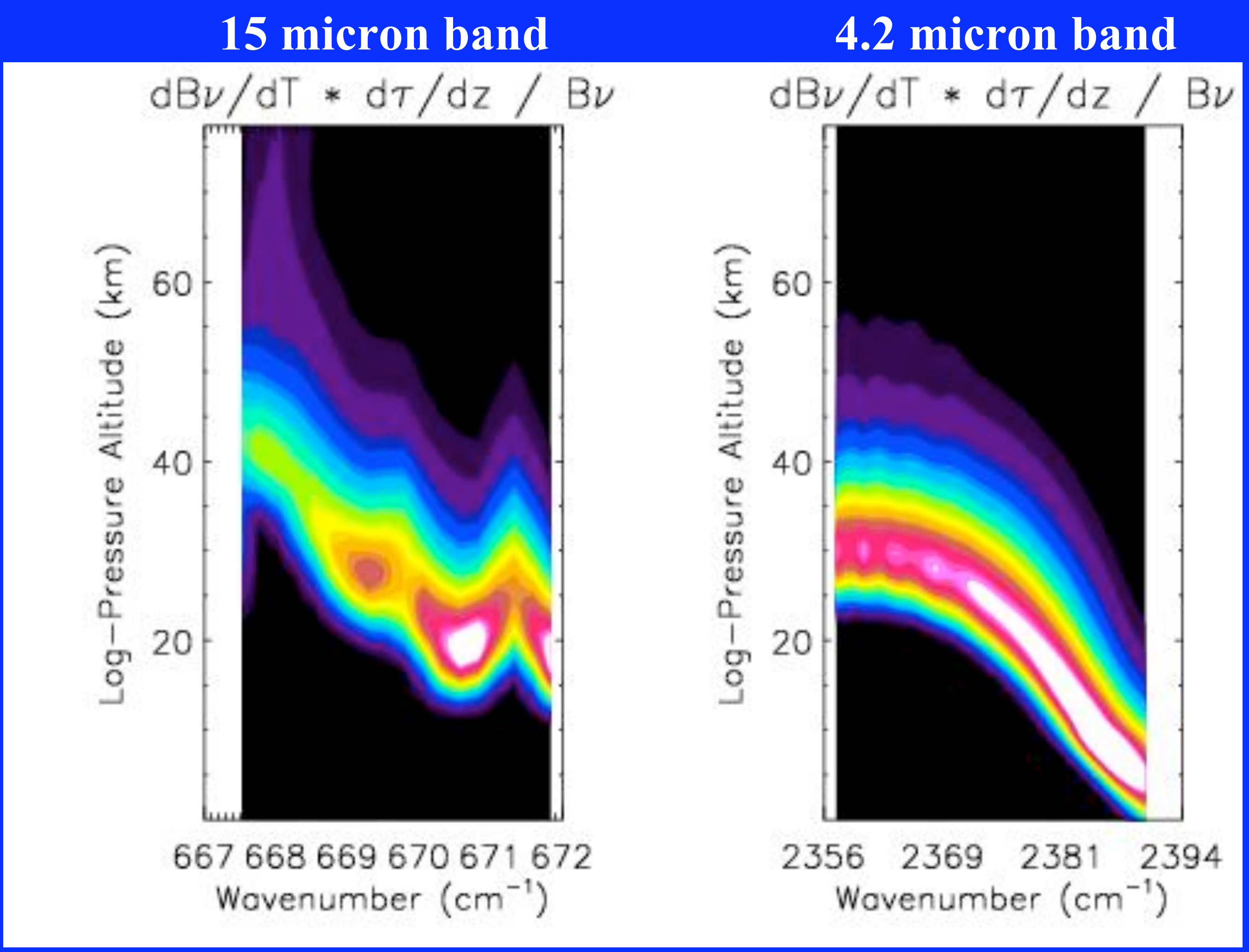
- **There is therefore a tendency to overemphasize the slow wave in long-term averaged data.**

Momentum Flux ~ (k/m) x Temperature Variance

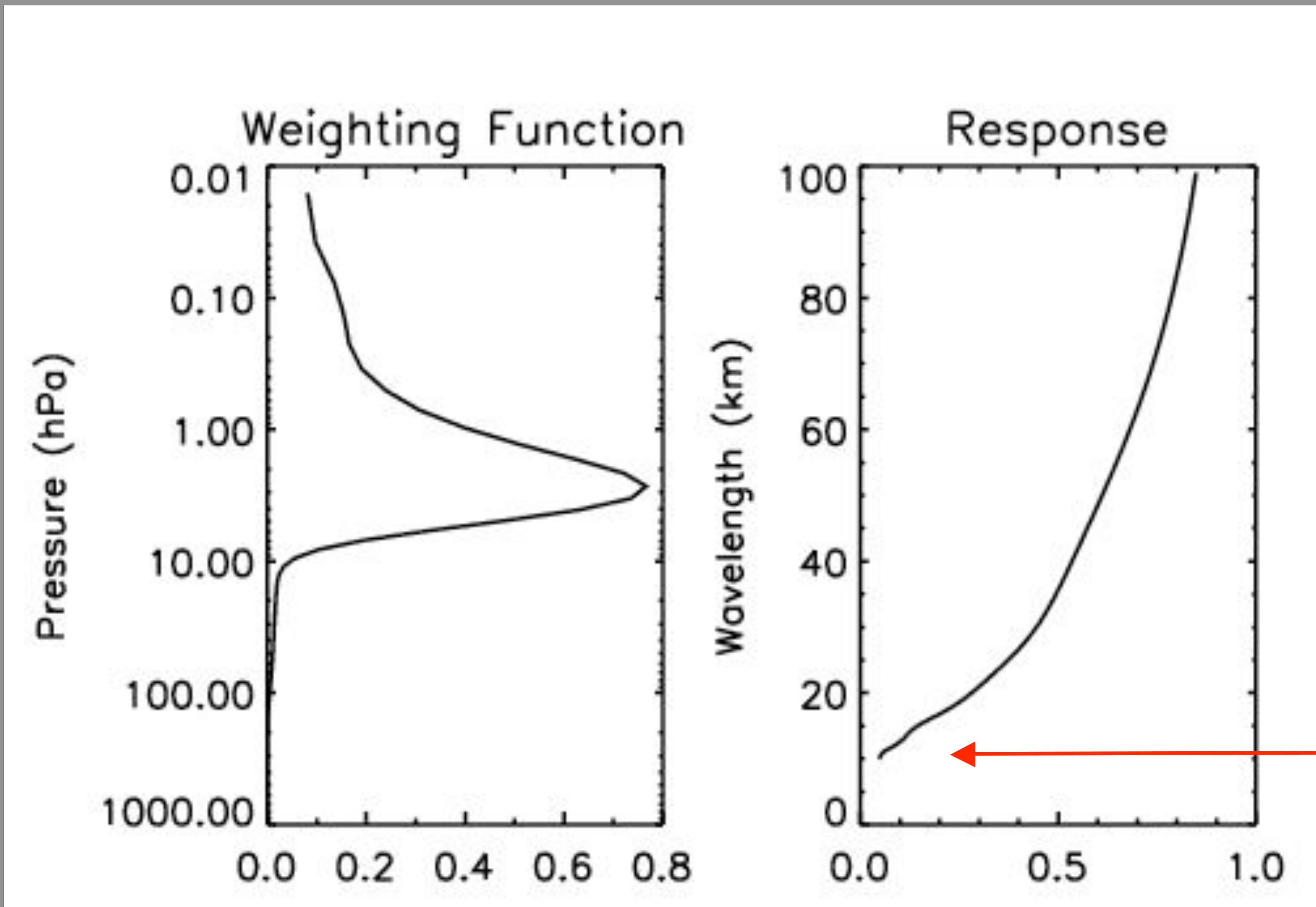
- **Fast waves will supply a disproportionate share of the global gravity wave momentum flux.**

In collaboration with Chris Barnet, we are examining AIRS radiance in two CO_2 emission bands in the stratosphere

Kernel Functions



Focus on the 667.77 cm^{-1} AIRS Channel in the 15 micron band

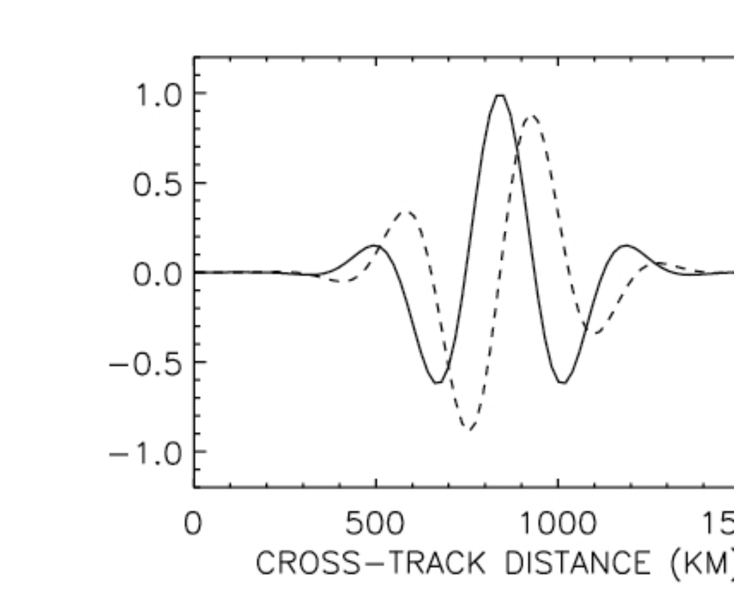


The depth of the weighting functions and the near-nadir view angles of AIR mean there will be little or no response to waves with vertic wavelengths less th 12 km.

AIRS => **F**ocus on long vertical scale, short horizontal scale waves
= Fast Waves!
=> Show horizontal propagation direction and resolve the short horizontal scale waves undersampled in previous measurements

Wave Identification Analysis:

- We perform a wavelet analysis in the cross-track *x*-direction using the S-transform wavelet (Stockwell et al., 1996)



- For each cross-track row (*x*) of AIRS data:

  -Interpolate to constant resolution = 18.9km.

  -Compute the S-Transform of each row.

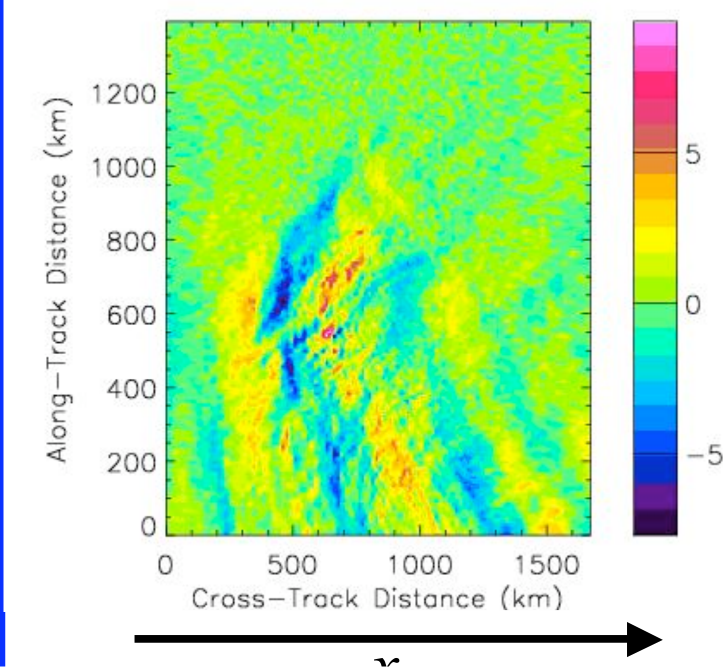
  -Compute the cospectrum between adjacent rows => (amplitude, phase).

  -Compute the average cross-track covariance spectrum of the AIRS Granule.

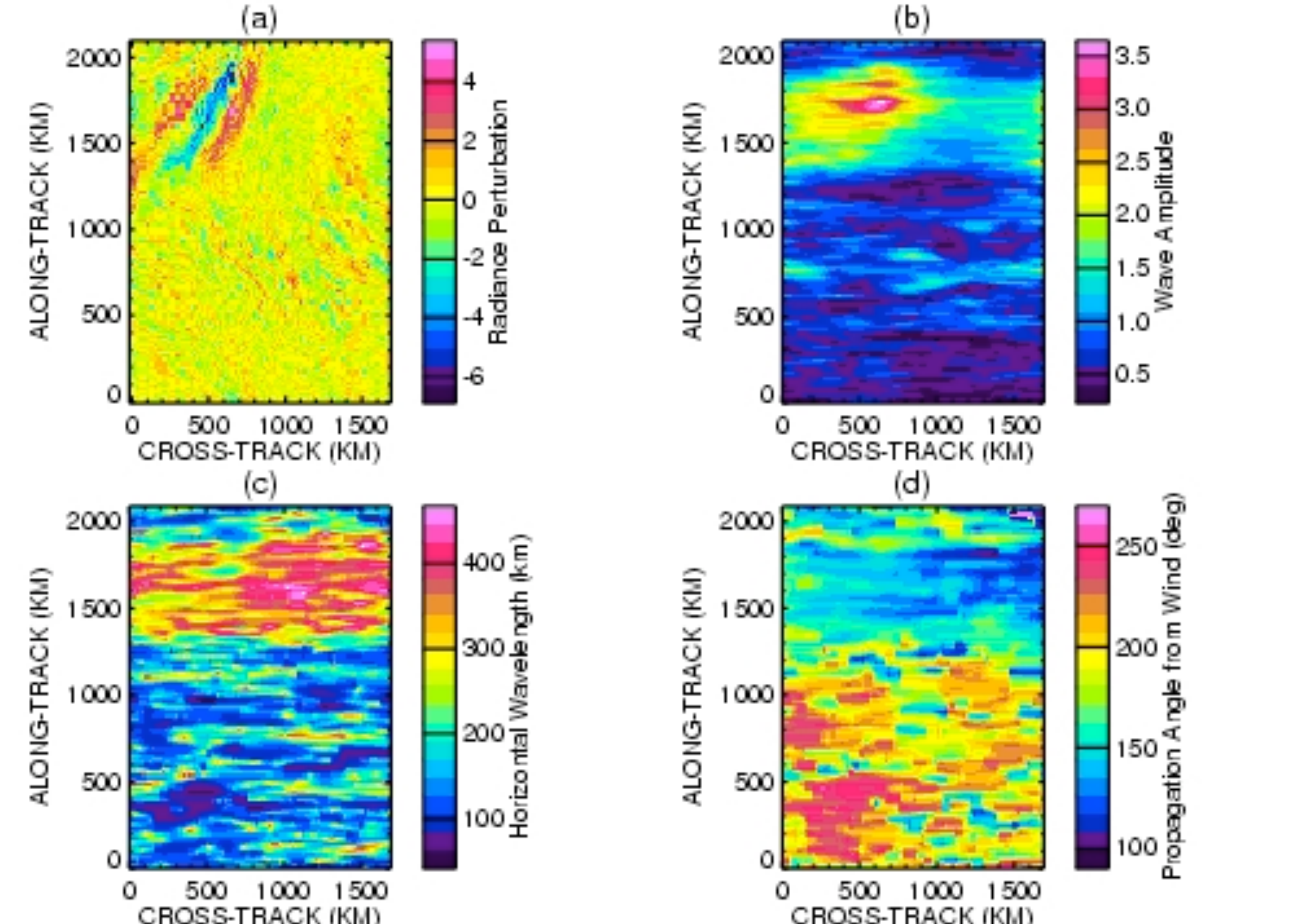
  -Find the peaks in this average spectrum.

  -Store amplitude(*x*,*y*) phase(*x*,*y*) for these dominant scales.

  -Use the phase shift between rows to compute the amplitude-weighted *y*-wavelength (*x*,*y*).

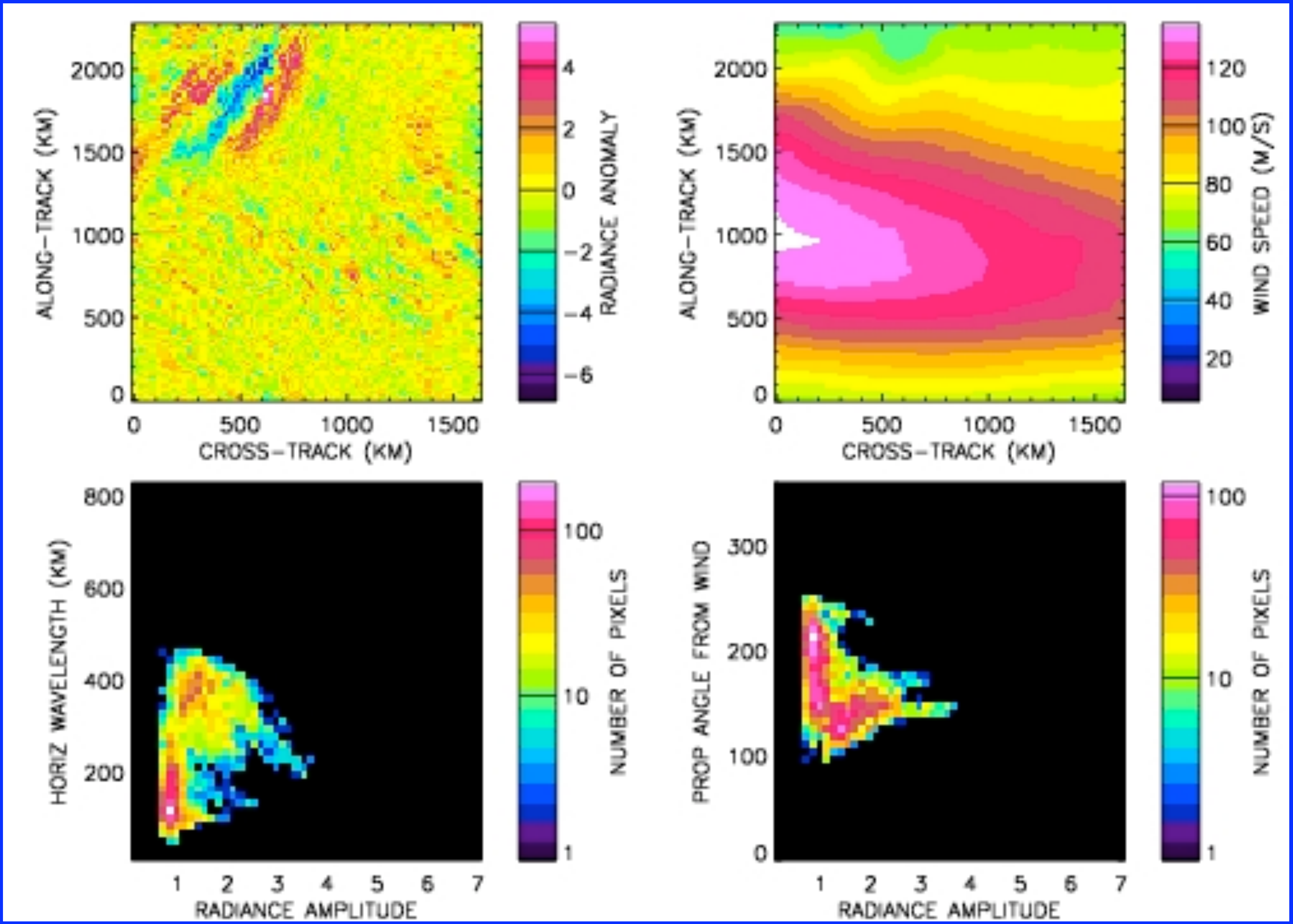


S-Transform Results (raw) Sep 10, 2003 Granule 4



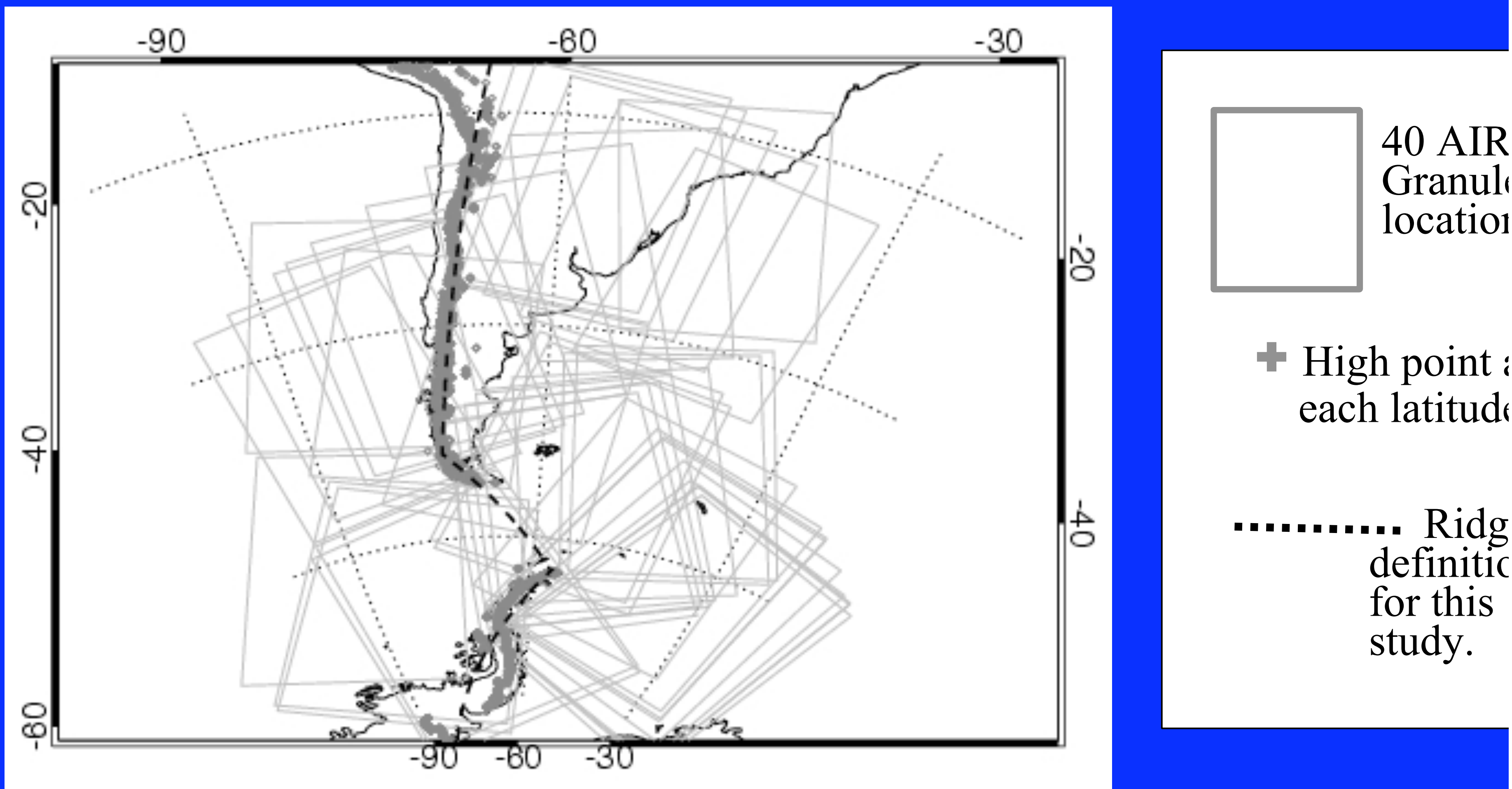
WAVE ANALYSIS STATISTICS

Sep 10, 2003 Granule 4



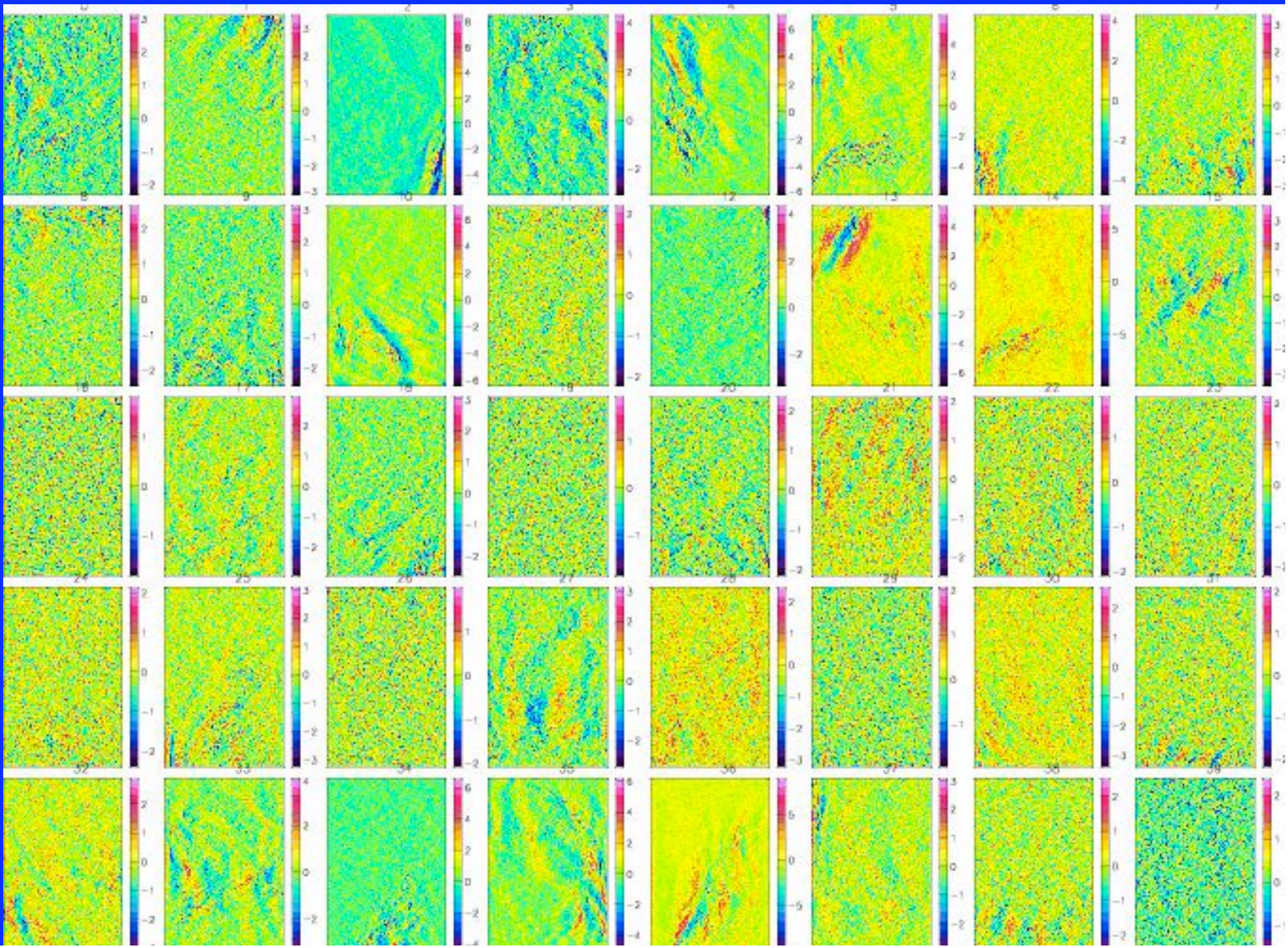
Mountain Wave Study

Select All Granules intersecting -56<lat<-36, -76<lon<-56
Month of September 2003



All Granules (-56<lat<-36, -76<lon<-56): September 1-30, 2003

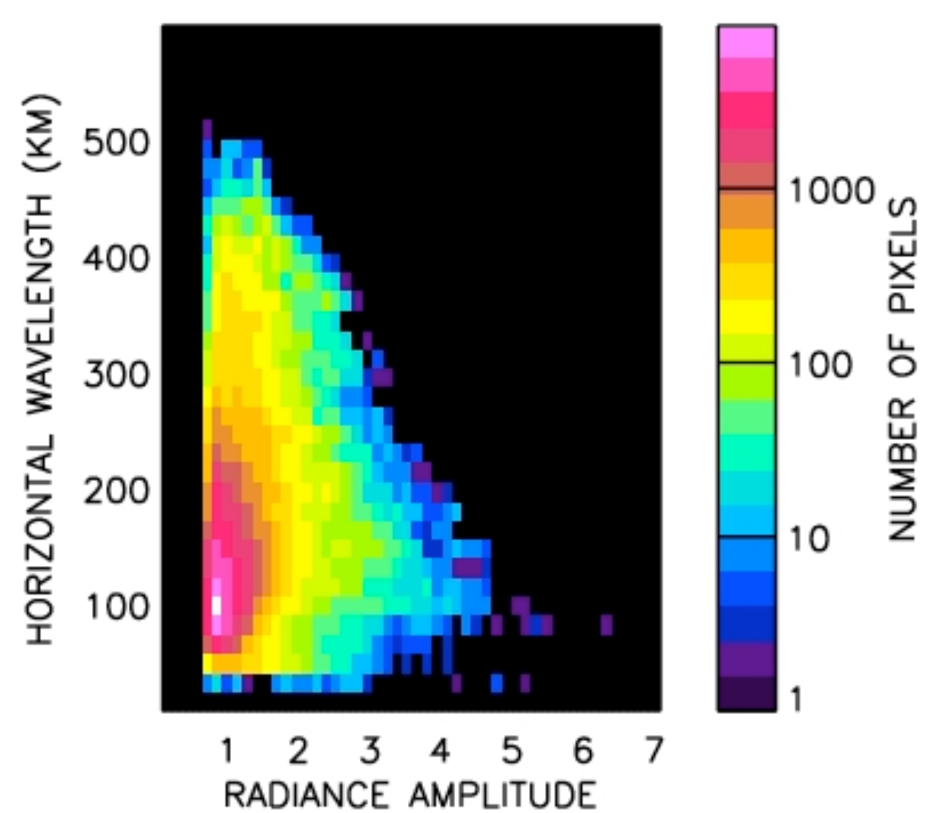
(40 Granules = 486,000 data points)



All Granules (-56<lat<-36, -76<lon<-56): September 1-30, 2003

Distribution of wave amplitudes and their horizontal wavelengths:
(Total of 40 granules)

- Most wave events have short wavelengths, ~ 100km.
- A distribution of wavelengths is observed ranging up to 500 km.



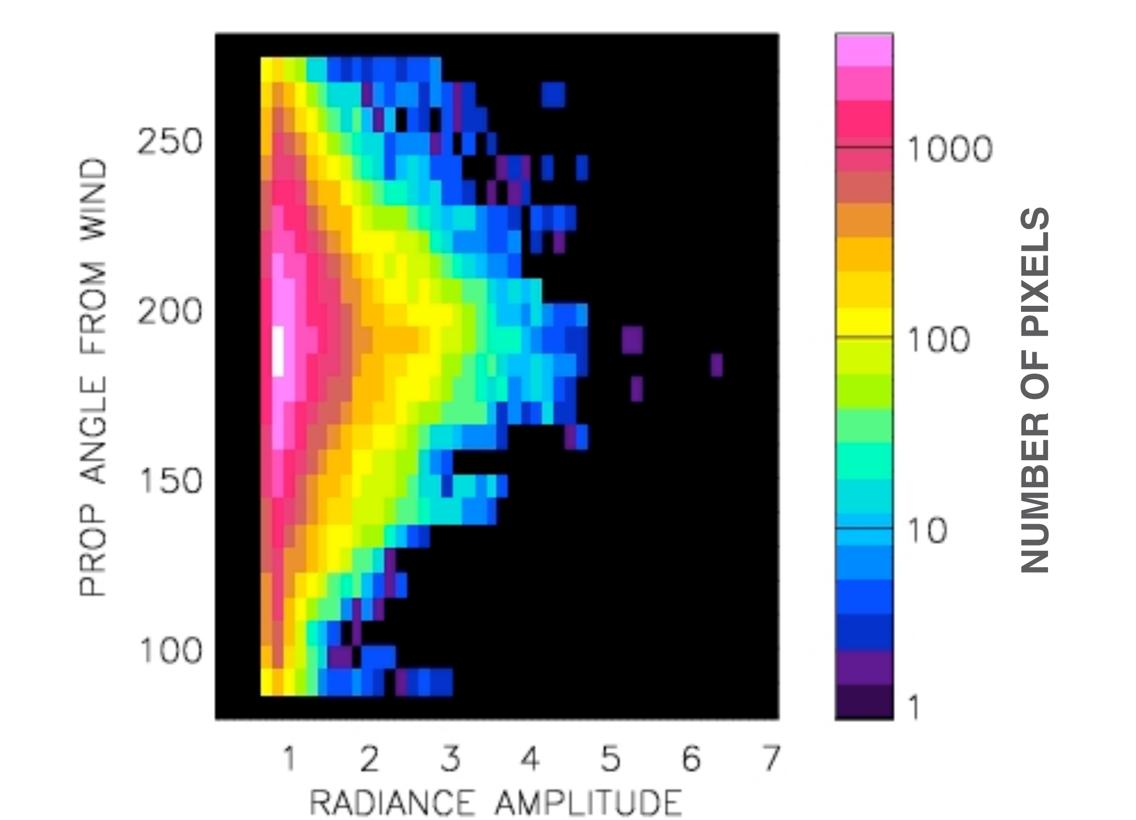
All Granules (-56<lat<-36, -76<lon<-56): September 1-30, 2003

Distribution of wave amplitudes and their propagation direction relative to the background wind: (Total of 40 granules)

- The most favorable angle would be 180°.

- The distribution peaks at an angle of 185° for weak events. The "weak events" that occur far from 180° are likely stronger events with short wavelengths that are highly attenuated.

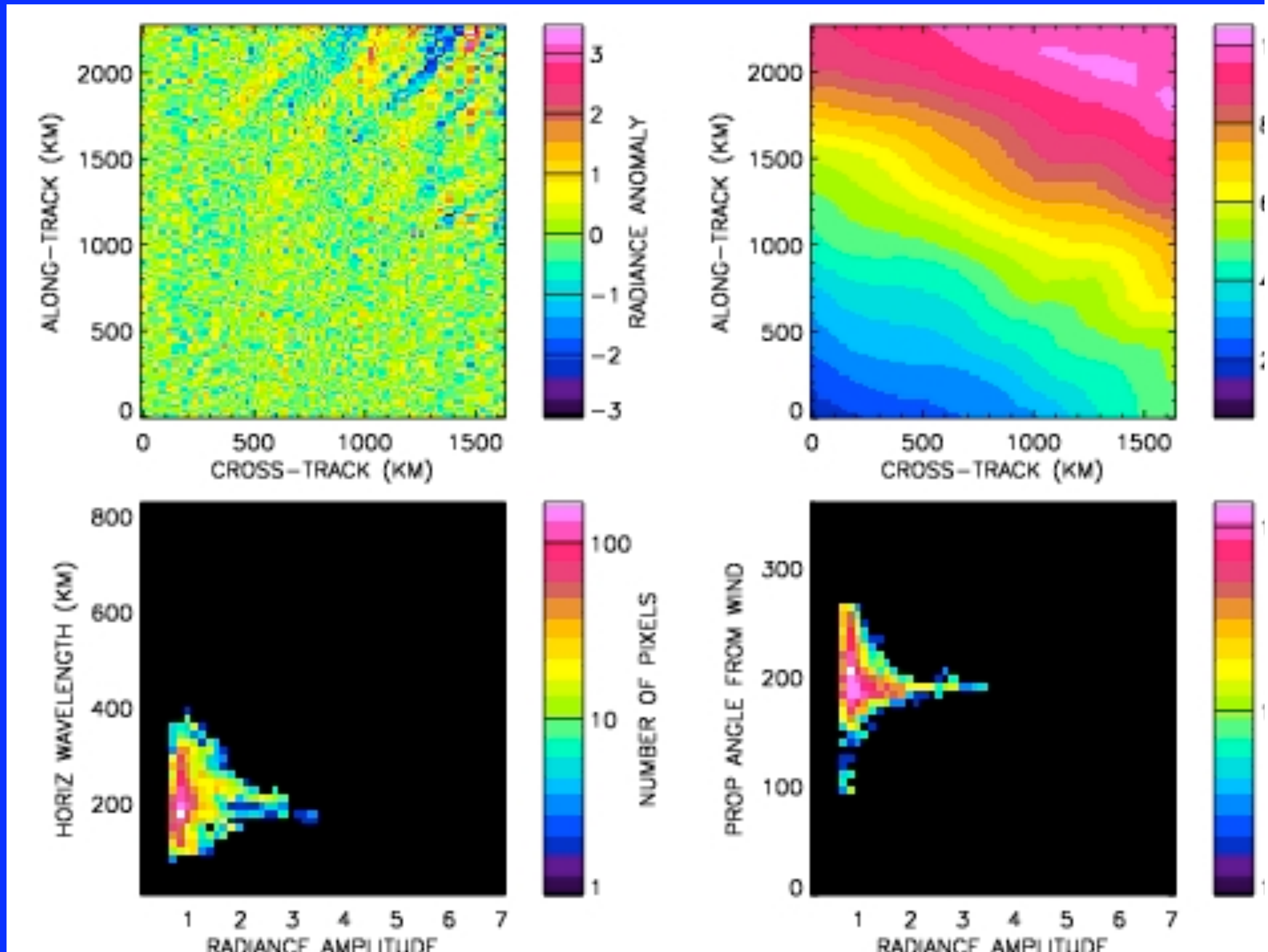
- Strong events are fewer in number, but also peak near 180°.



Background Wind Effects on Visibility of the Waves

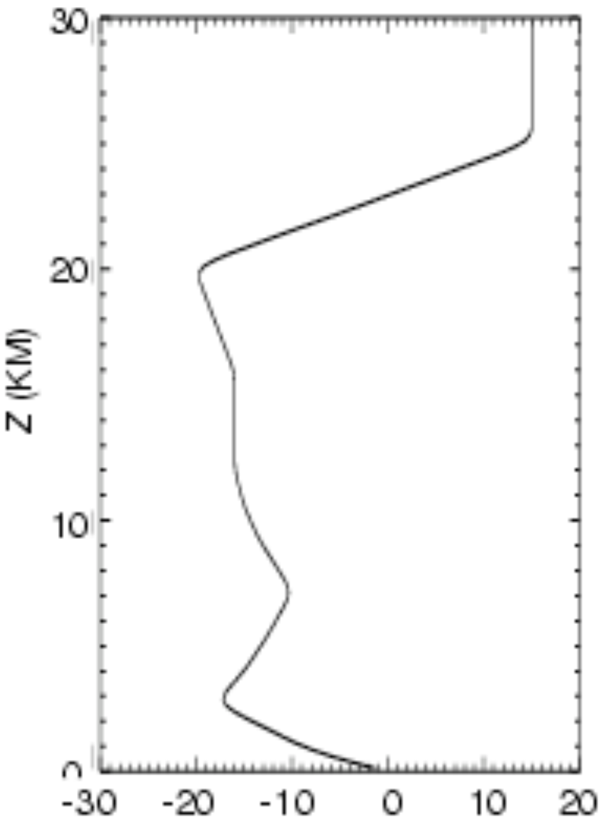
Example: Sep 1, 2003 Granule 196

Waves appear only in strong winds and propagate in the direction ~190 degrees upstream of the wind direction.

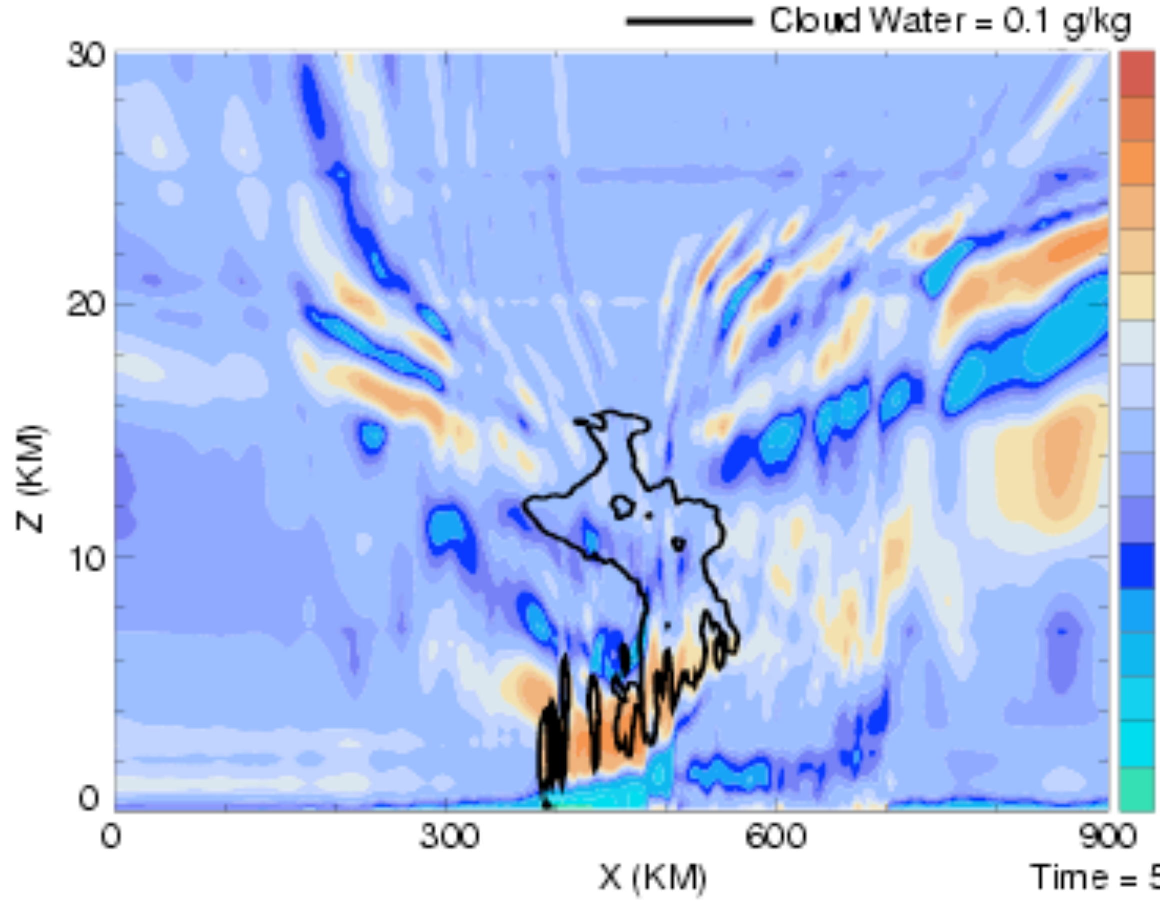


Doppler-Shifting / Refraction Effects

Strong Stratospheric Shear

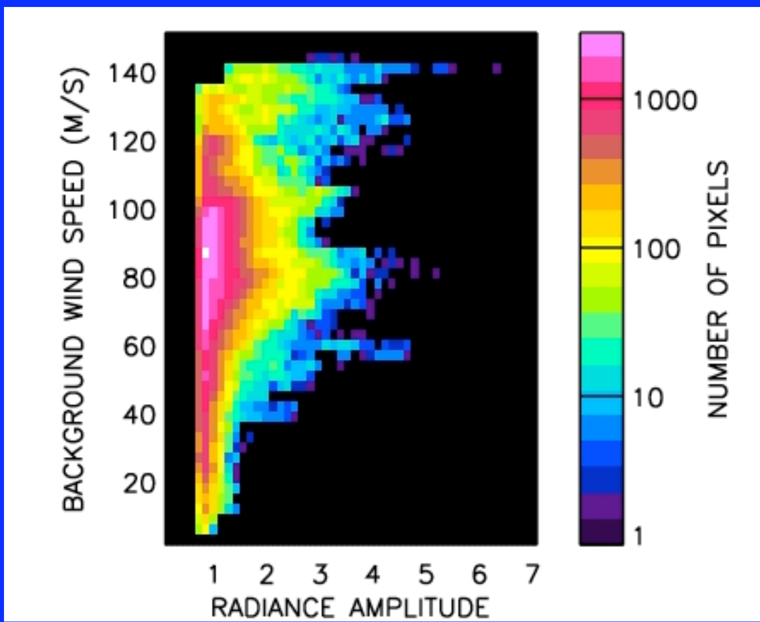


Simulation of gravity waves generated by convection showing refraction of waves in the stratosphere :

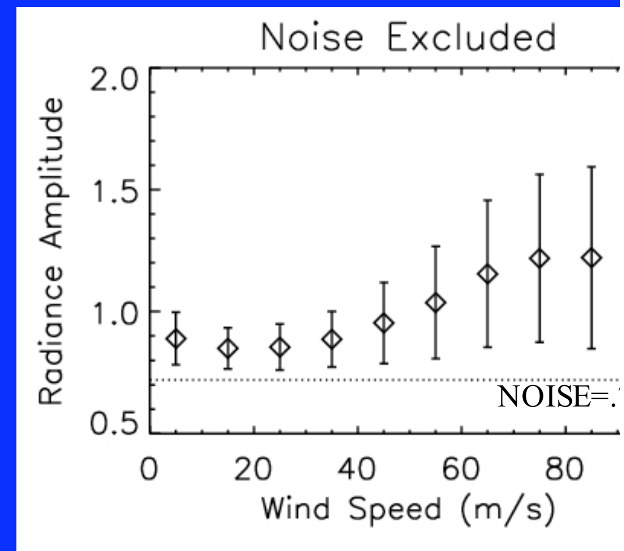


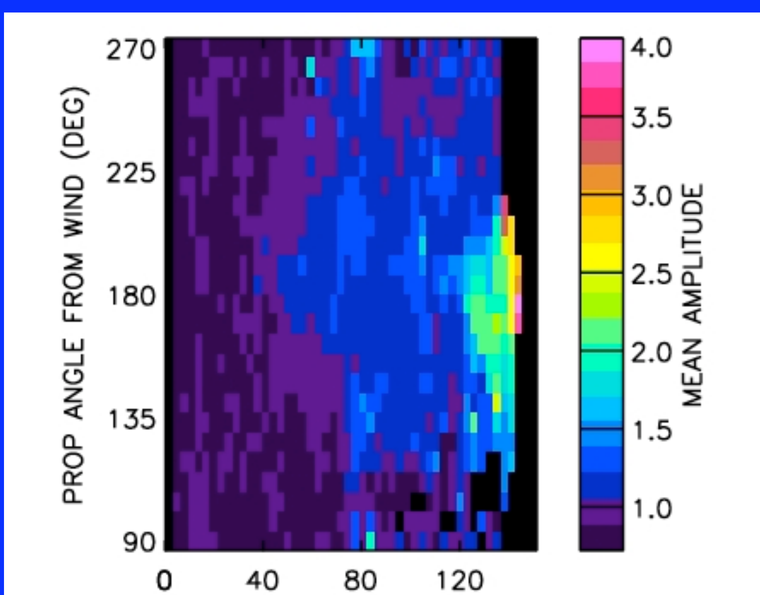
(from Alexander and Holton |

Data from all granules show wave amplitudes increase dramatically wherever background winds exceed 40 m/s.



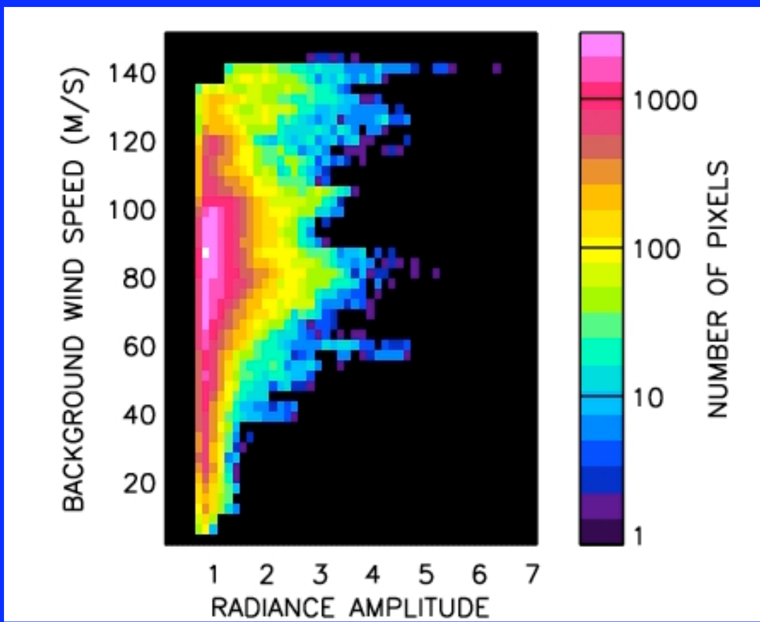
Average amplitude shows an increasing trend where background winds exceed ~ 40 m/s.

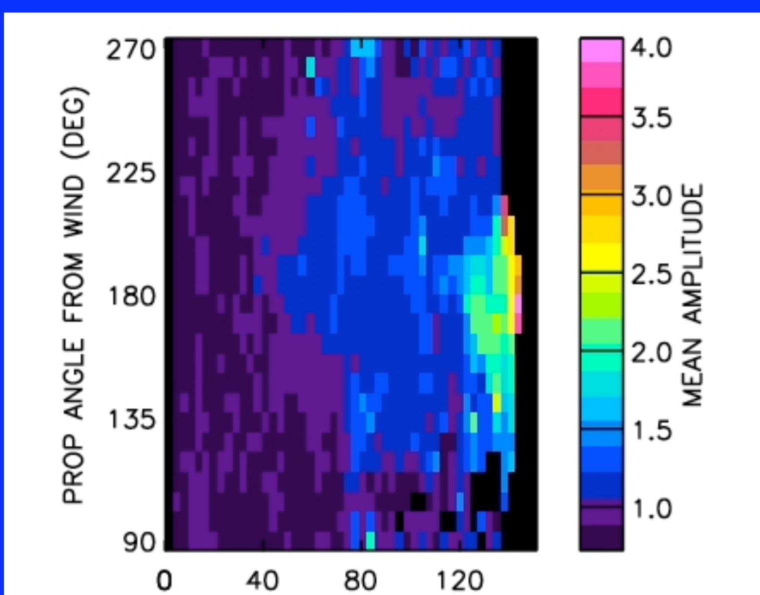




For a given background wind speed, the average wave amplitudes are also largest when the waves propagate perpendicular to the background wind.

Data from all granules show wave amplitudes increase dramatically wherever background winds exceed 40 m/s.





40 m/s is a magic number for seeing mountain waves in AIRS data:

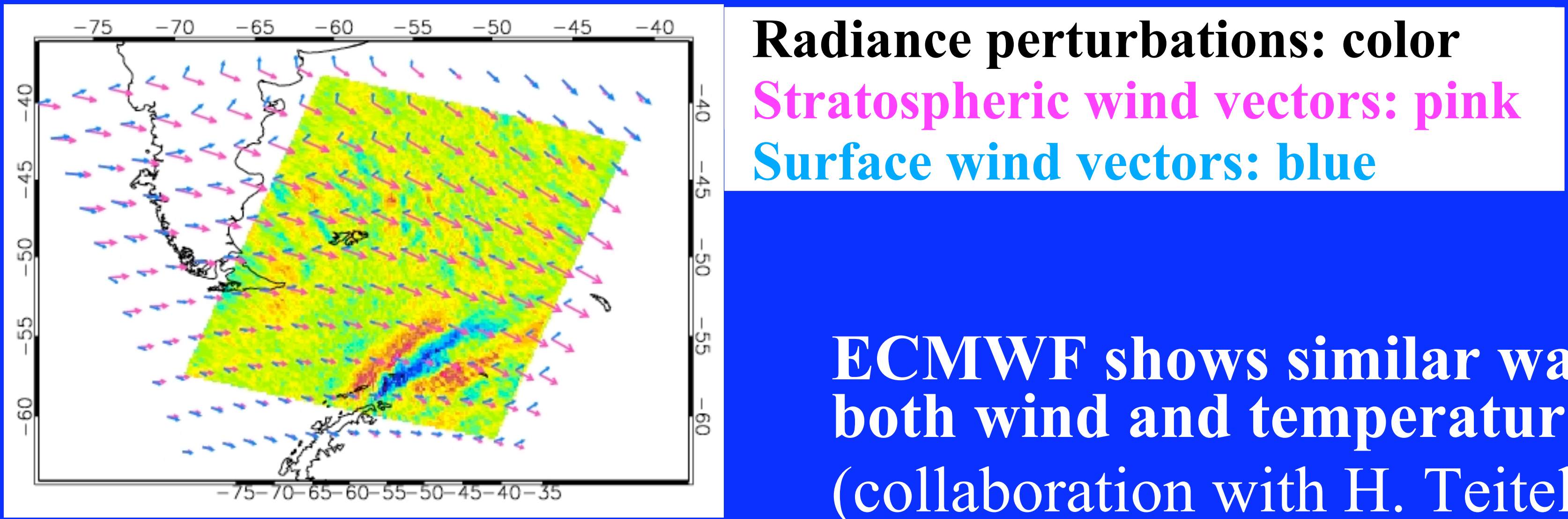
* Minimum vertical wavelength λ_z = 12km

* Mountain wave frequency $\omega_0 = 0$
phase speed $c_0 = 0$
intrinsic frequency $\omega = \omega_0 - Uk = -Uk$
intrinsic phase speed $c = c_0 - U = -U$

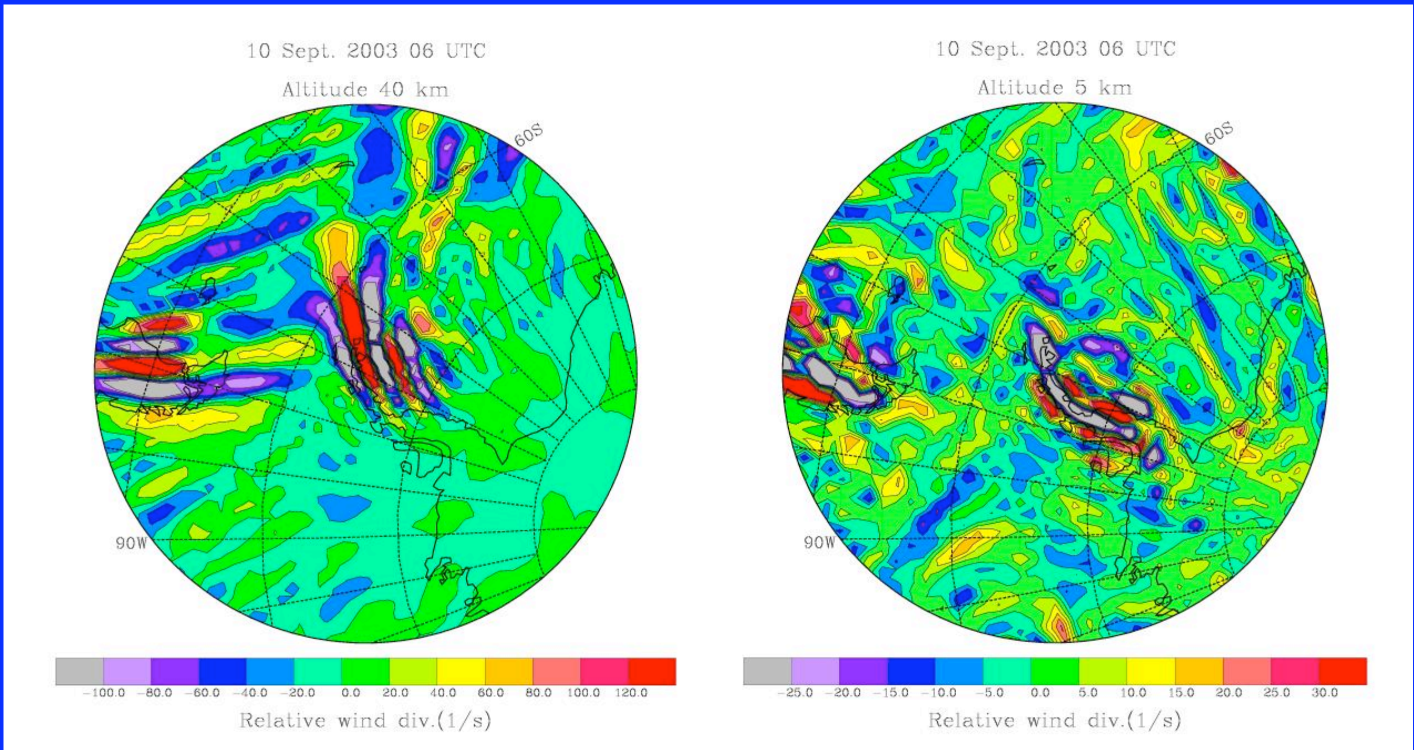
* Gravity wave dispersion relation (simplified form):
$|\lambda_z| = 2\pi|U|/N$

* N ~ .02 s^{-1} (roughly constant), so for
U = 40 m/s => λ_z = 12.5 km

Case Study: Sep 10, 2003 Granule 44



ECMWF shows similar wave in both wind and temperature fields
(collaboration with H. Teitelbaum)

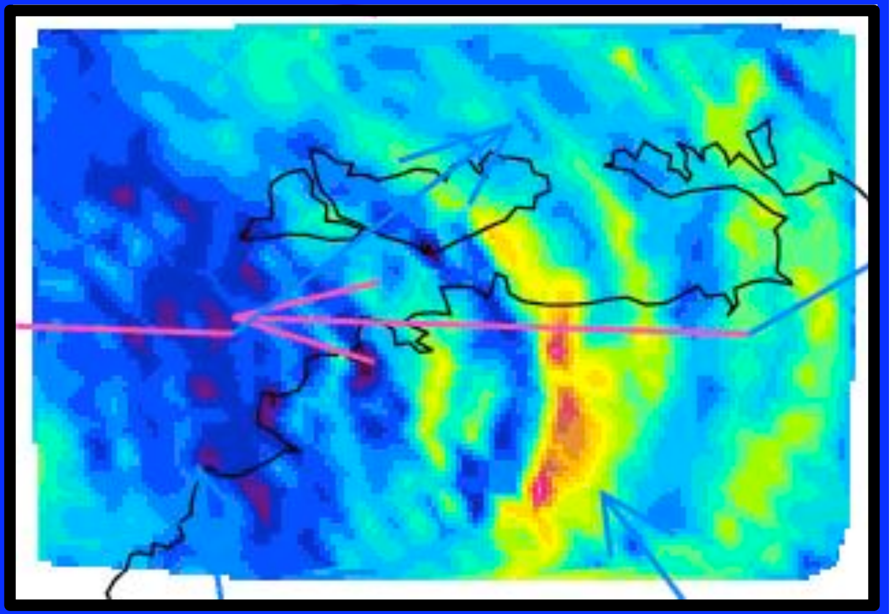


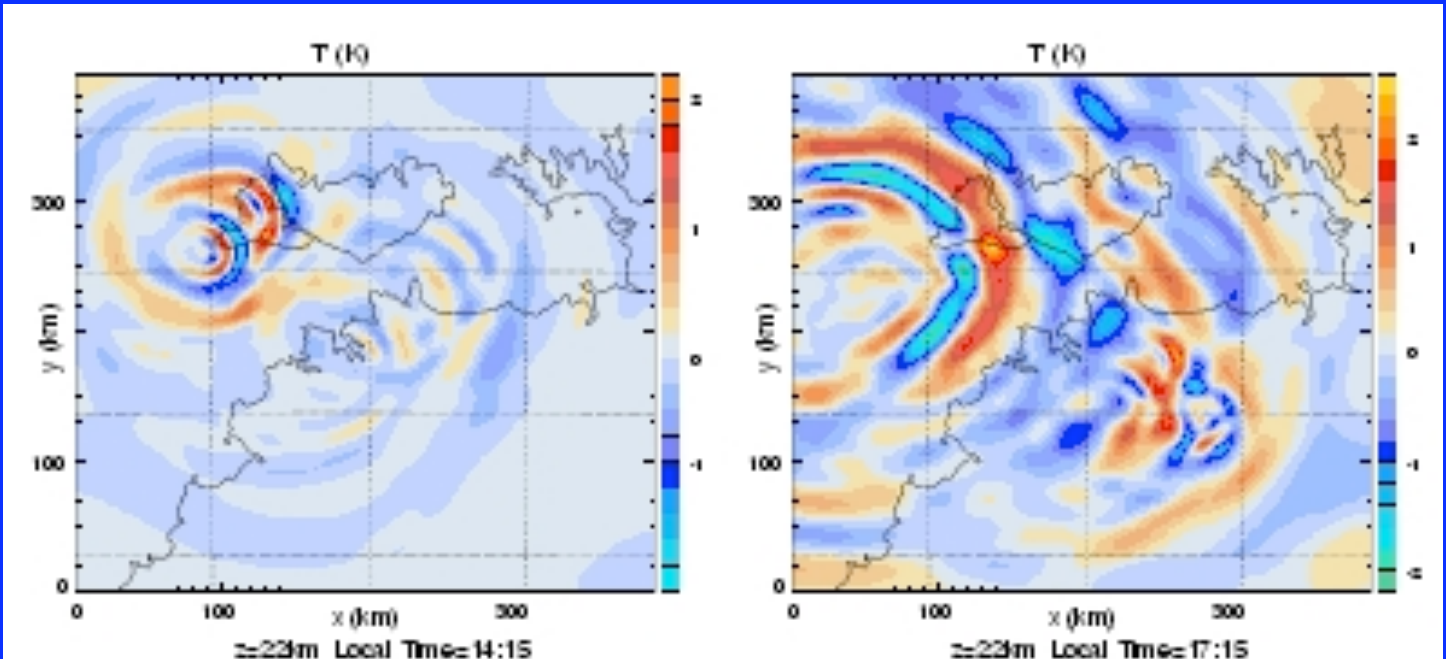
Wind divergence at 40 km (left) and 5 km (right)

Source traced to surface front east of the Antarctic Penninsula

Case Study: Jan 12, 2003 Granule 167

Waves generated by tropical convection over Darwin, Australia seen in AIRS radiances

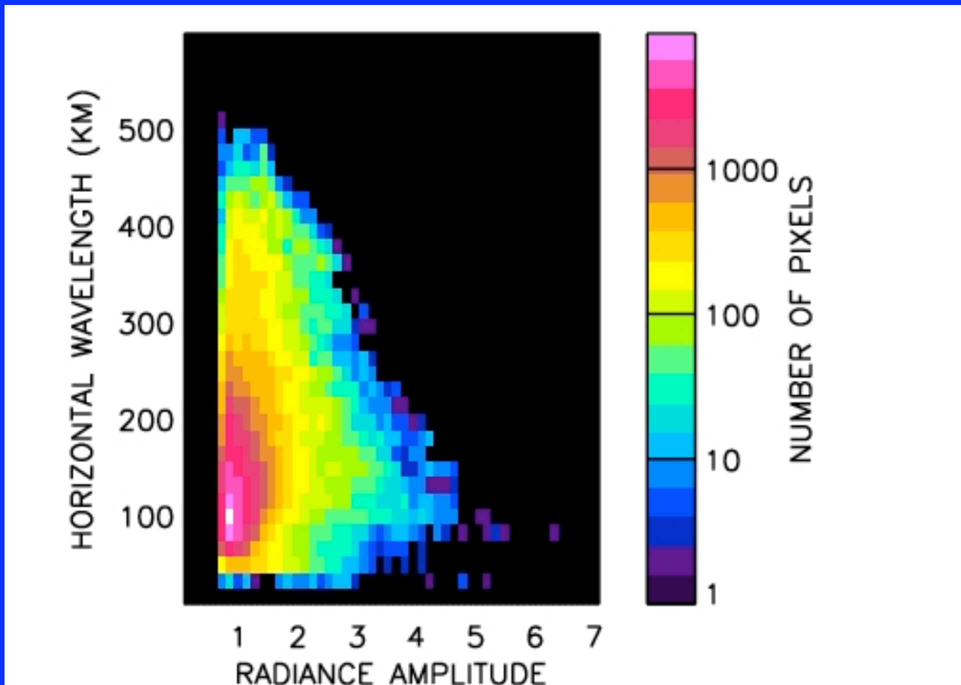




Ongoing work Model studies waves generat by Darwin-are convection.

Conclusions

- **Image data like AIRS offer opportunities to study wave events**



PDF of Patagonian mountain waves

- Give amplitudes, wavelengths, and propagation directions at high horizontal resolution.

- AIRS observations can be compared to detailed wave source models and used to improve those models and constrain parameterizations.

- Current data are limited to only long vertical wavelength waves, which also have high horizontal phase speeds, fast propagation speeds and a high degree of intermittency.

- Such waves are underestimated in global averaged data but may carry a large fraction of the net gravity wave momentum flux.